Digging Deeper at Long Wavelengths

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Digging Deeper at Radio Wavelengths

- Case studies
  1. Fundamental physics from pulsar observations and pulsar surveys
  2. The Dynamic Radio Sky
     a) “Fast” Radio Transients
     b) “Slow” Radio Transients
  3. Gravitational Wave Detection and Study

     … or special case of #1

Science Pathfinding for the Square Kilometre Array


- SKA is ultimate goal, though long-term program
- Precursors and many pathfinders in existence or under construction

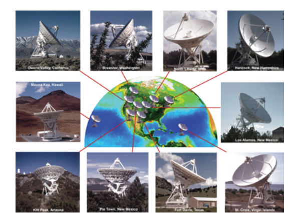
➢ Data challenges before SKA comes on-line

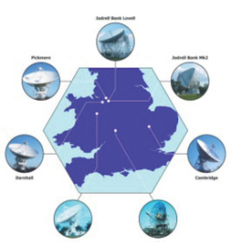
➢ Scalability could be an issue

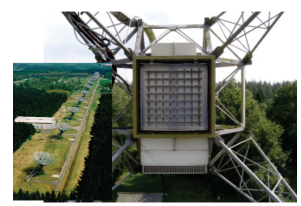






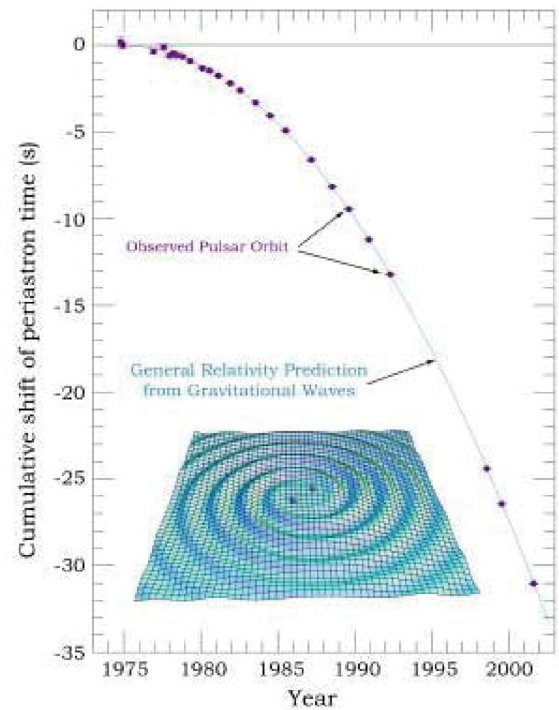




Case Study: Fundamental Physics with Radio Pulsars

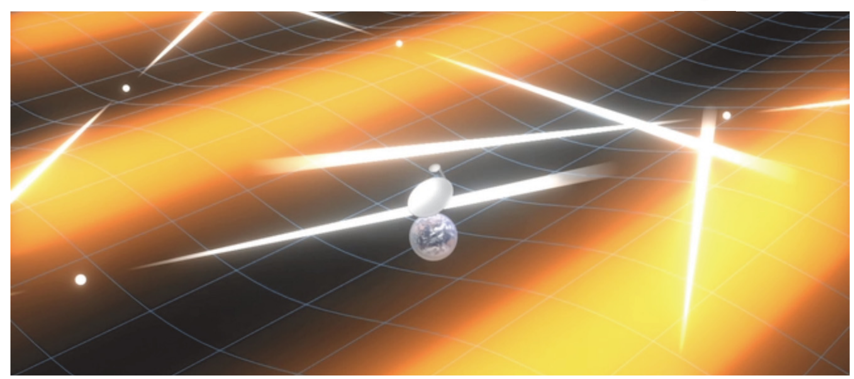
Arrival times of pulses from radio pulsars can be measured with phenomenal accuracy

- Better than 100 ns precision in best cases
- Enables high precision tests of fundamental physics
  - Theories of gravity, gravitational waves, nuclear equation of state
  - 1993 Nobel Prize in Physics
- **Problem**: Not all pulsars are equal!
- Good "timers" < 10% of total population
- Need to find many more!

➢ All-sky survey

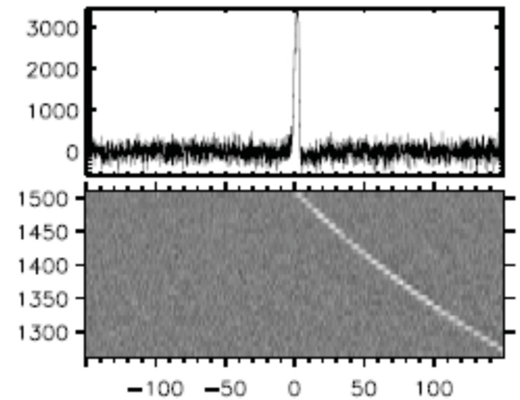


← Ultra-relativistic binaries & gravitational wave studies



Processing Considerations I

1. For each pixel (α, δ), observations produce 2-dimensional matrix of power as a function of (ν, t):



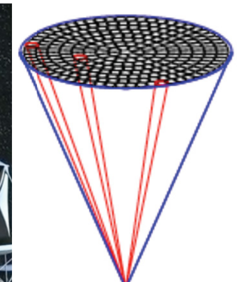
– Accumulate data for a time Δt over a bandwidth $\Delta\nu$

Suppose Δt = 20 min, $\Delta\nu$ = 800 MHz

– Time sampling δt with frequency channelization $\delta\nu$

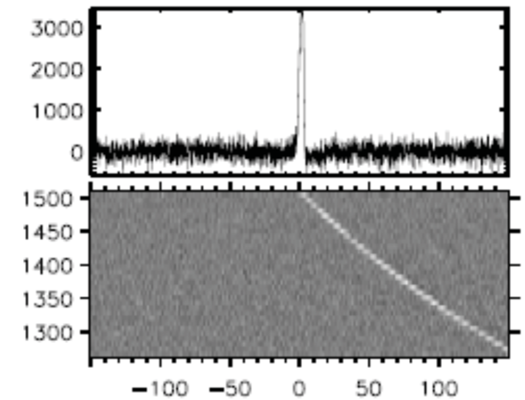
For GBT GUPPI, δt = 81.92 ms, $\delta\nu$ = 24 kHz

– Data sets ~ $10^7 \times 10^4$ matrices ➔ 60 GB data sets per pixel …



Processing Considerations II

1. For each pixel (α, δ), observations produce ~ $10^7 \times 10^4$ matrix of power as a function of (ν, t):

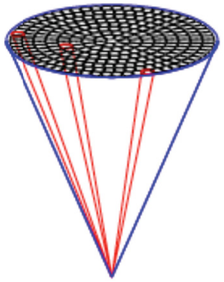


2. Unknown dispersion measure (DM) and period (P)
   a. For trial DM, compensate for frequency chirp and integrate over frequency (de-disperse)

      10^4 trial DMs?

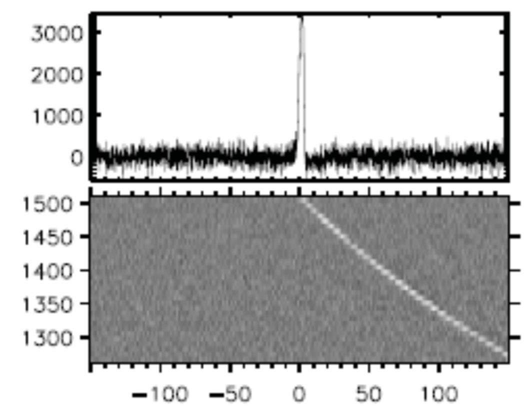
   b. FFT each de-dispersed time series, look for peaks or sum harmonics (to find P)
   c. Search for accelerations or frequency drifts

      "run out of computing capability *way* before we run out of interesting parameter space …."

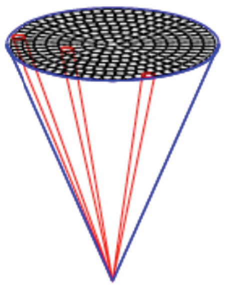


Processing Considerations III

1. For each pixel (α, δ), observations produce ~ $10^7 \times 10^4$ matrix of power as a function of (ν, t):



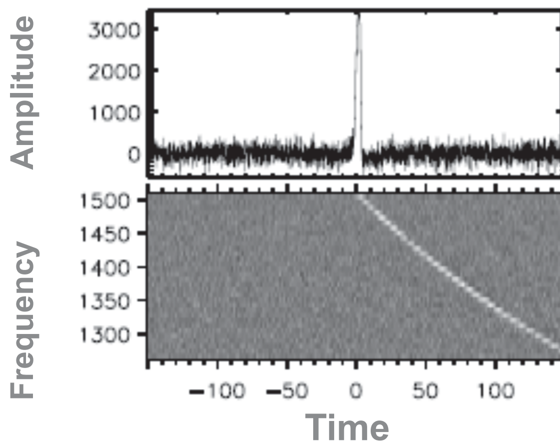
2. Unknown dispersion measure (DM) and period (P)
3. Want to access entire field of view or number of pixels
   - Traditional single dish telescope = 1 pixel
   - Parkes Multi-Beam system or Arecibo ALFA ~ 10 pixels
   - Future GBT phased array feed ~ 100 pixels?
   - EVLA or MeerKAT ~ 10^3 pixels
   - ASKAP > 10^4 pixels
   - Arrays introduce another level of complexity or freedom



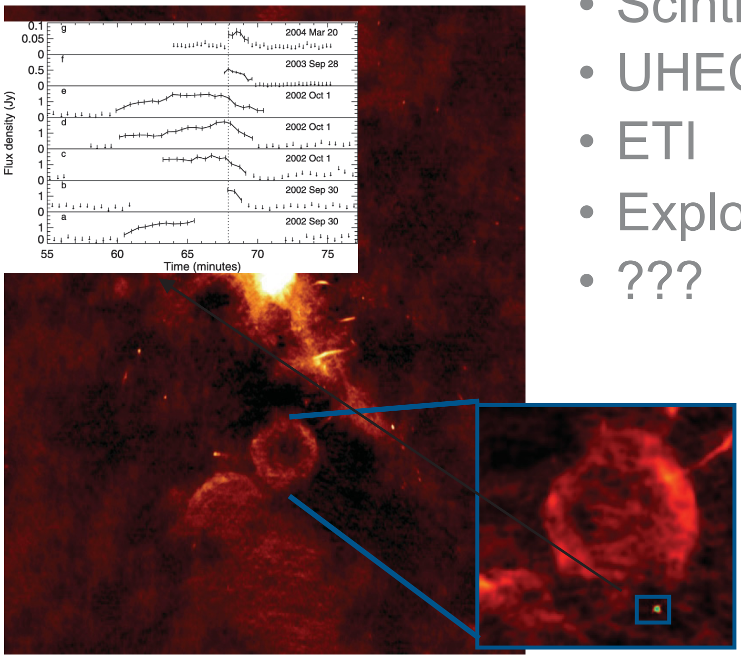
Case Study: The Dynamic Radio Sky

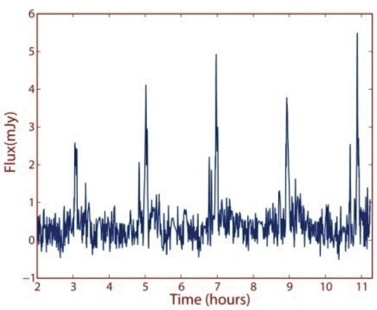
- Neutron stars
  - Magnetars
  - Giant pulses
  - Short GRBs?
- Microquasars

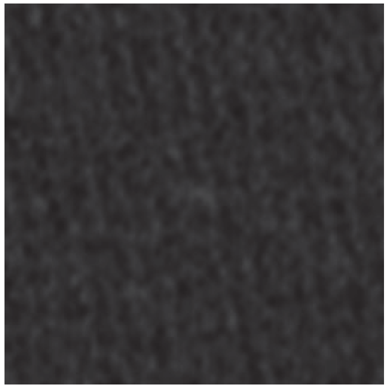
- GRBs (γ-ray loud; γ-ray quiet?)
  - Afterglows
  - Prompt emission?
- Sub-stellar objects
  - Brown dwarfs
  - Extrasolar planets?
- Scintillation
- UHECRs
- ETI
- Exploding black holes
- ???



Rotating Radio Transients (RRATS)







Pulsating Brown Dwarfs

Radio Transients

SQUARE KILOMETRE ARRAY

Coherent ("Fast")

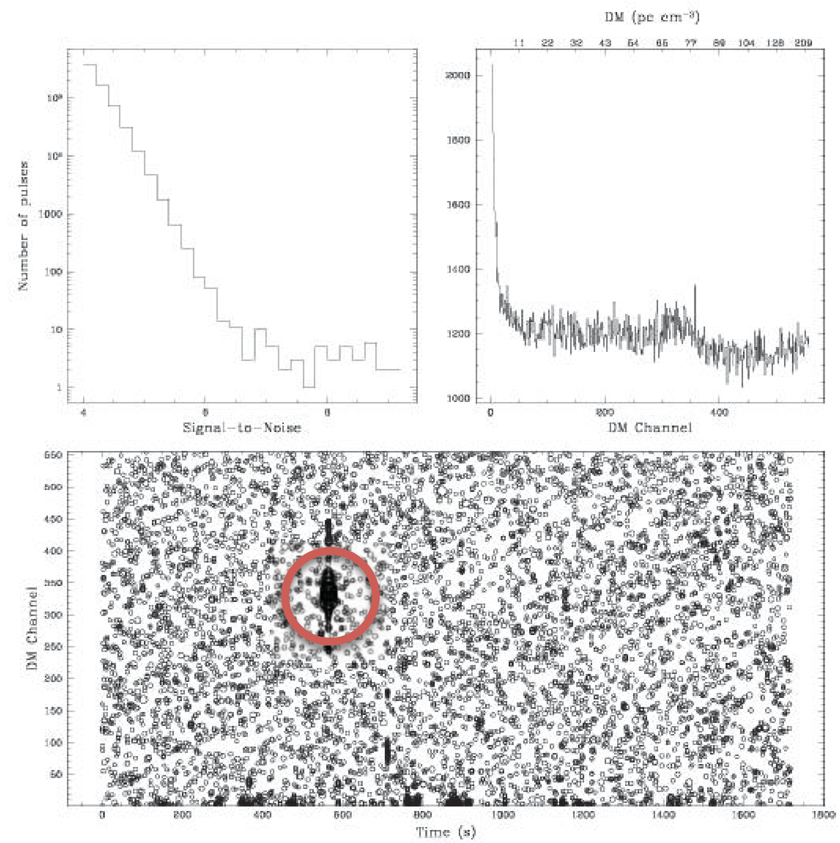
- Generated by particles radiating in phase
  - $L \propto N^2$
- Tend to be at lower frequencies
  - Radiating volume $\propto \lambda^3$
- Propagation effects generally important
  - De-dispersion required
- $W < 1$ s
  - Real-time processing probably required

Incoherent ("Slow")

- Generated by independent particles
  - $L \propto N$
- Tend to be at higher frequencies
- Propagation effects generally unimportant
  - De-dispersion not required
- $W > 1$ s

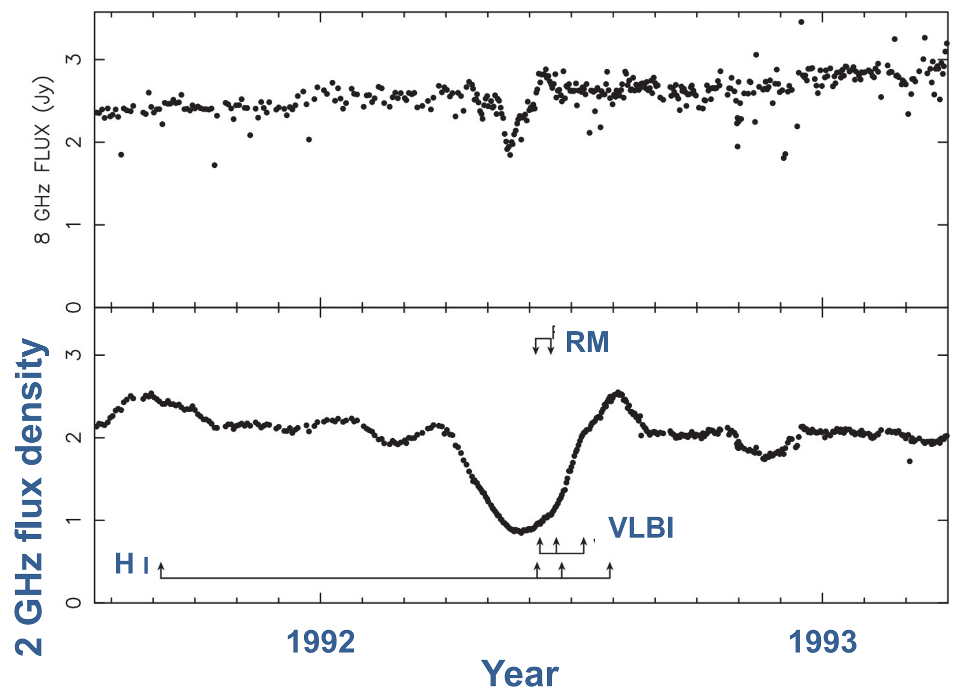
Coherent (“Fast”) Transients

- Bursts from neutron stars, evaporating primordial black holes?, prompt emission from γ-ray bursts? …?
- See pulsars
  - …but periodicity and acceleration aspect of search **not** important



Slow ("Incoherent") Transients

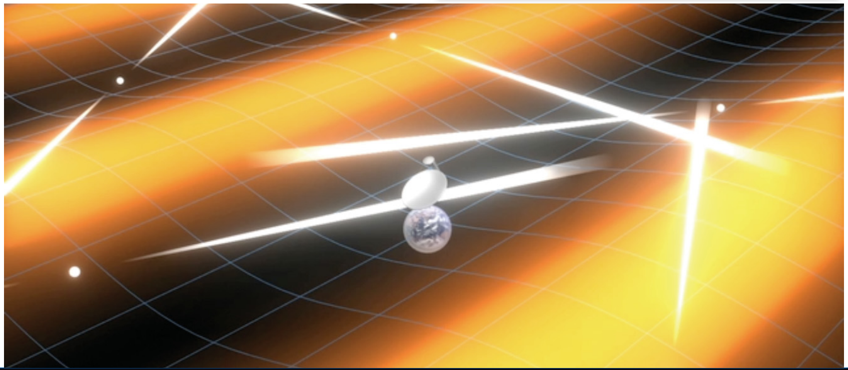
- Find all sources in (noisy) image
  …or in transform plane.
- Measure flux density (brightness).
- Cross-correlate sources with previous epoch and/or other wavelength data.
  – Classify light curves
  – Identify on-going events

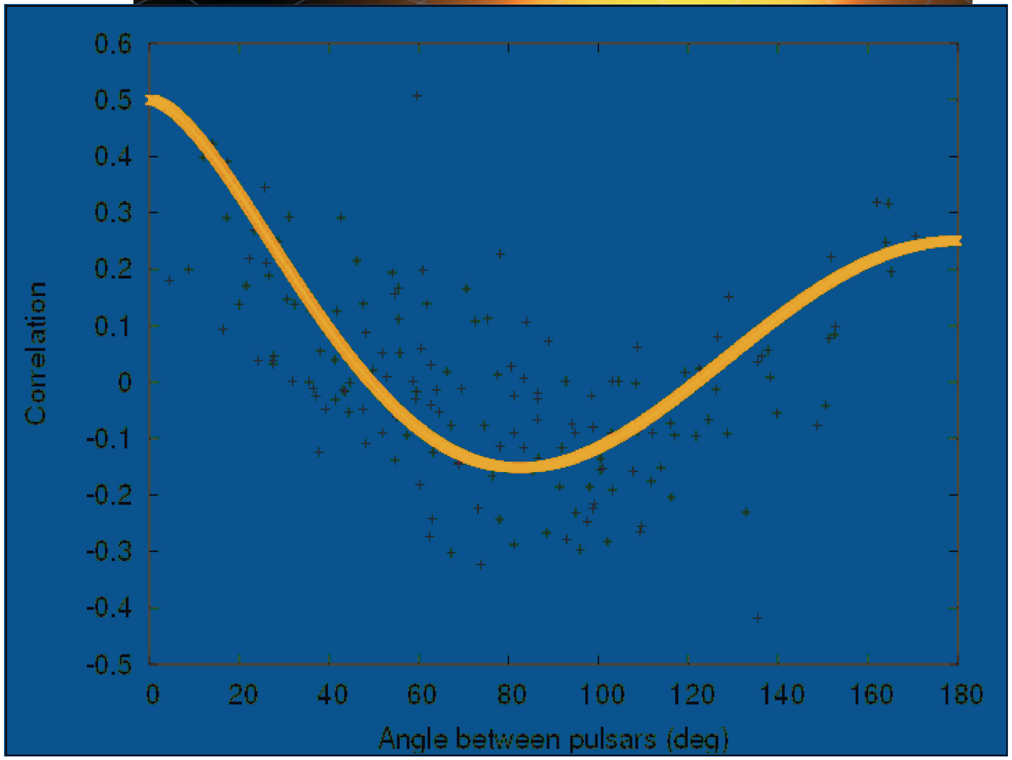


Gravitational Wave Studies

- Sea of gravitational waves washing over Earth
- Expected correlation around the sky
- N=20 pulsars with σ =100 ns timing noise

(Hellings & Downs 1983; Jenet et al 2005)

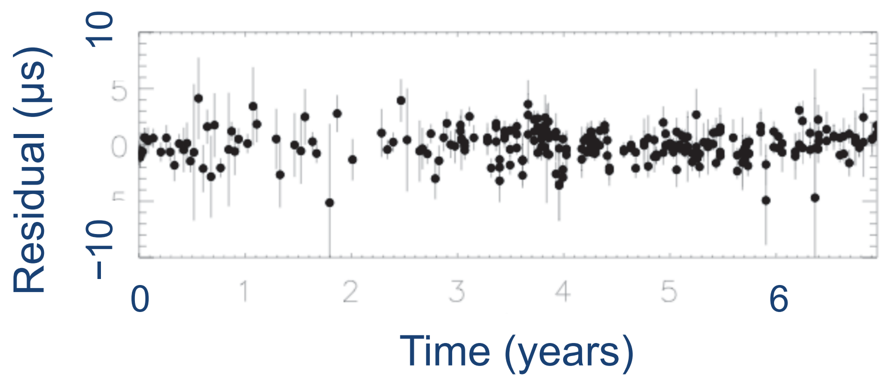




Gravitational Wave Detection

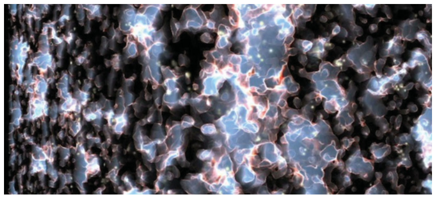
- Measure time of arrival (TOA) of pulse at observatory
- Form residuals from expected TOAs
- Residual time series contain both “white” and “red” noise
  - Measurement uncertainties
  - Model uncertainties
  - Intrinsic rotational “jitter” of pulsars
  - …
- Modest number of time series

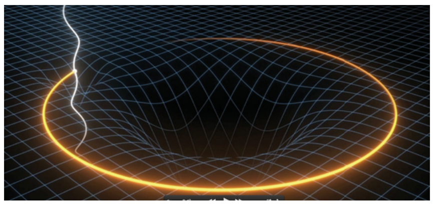
  < 100
- Low cadence
  - ~ 2 data per month
  - Higher cadence “campaigns” might be justifiable

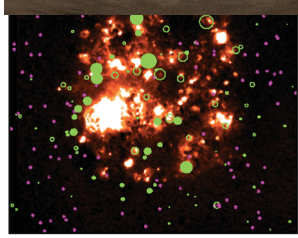


(Kaspi, Taylor, & Ryba 1994)

Summary – Digging Deeper at Radio Wavelengths







- Exciting science!
- Leads to exciting processing challenges
  - Pulsar Surveys and “Fast” Transients (real-time, wide-field processing)
  - “Slow” Transients (source finding, time series classification)
  - Gravitational Wave Detection and Study (new algorithms)